Copy

CONFIDENTIAL

NASA TM X-621

NASA TM X-621

TECHNICAL MEMORANDUM

X-621

STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE

By Walter B. Olstad and Dewey E. Wornom

Langley Research Center
Langley Air Force Base, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON November 1961

CONFIDENTIAL

CONFIDENTIAL

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM X-621

STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE*

L
1
6
5
0

By Walter B. Olstad and Dewey E. Wornom

SUMMARY

Data are presented which were obtained from tests at Mach numbers M of 2.86 and 6.02 of a lenticular-shaped (double convex in cross section and circular in planform) reentry vehicle with and without movable fins. The tests were conducted at angles of attack from -10° to 95°. The Reynolds number, based on the body diameter, was about 0.28×10^{6} at $M = 2.86$ and about 0.54×10^{6} at $M = 6.02$.

The body-alone model with the center of gravity located longitudinally at 45 percent of the body diameter from the nose was stable at angles of attack greater than about 40° and trimmed at an angle of attack of about 67.5° at $M = 2.86$ and about 70.5° at $M = 6.02$. The value for the maximum lift-drag ratio for the body-alone model was about 0.79 at $M = 2.86$ and about 0.73 at $M = 6.02$. Addition of the fins at a deflection angle of 0° to the body-alone model increased the maximum lift coefficient 35 percent, and increased the maximum lift-drag ratio about 9 percent at $M = 2.86$ and about 6 percent at $M = 6.02$. Deflecting the movable fins gave the model a trim capability over the range from the angle of attack for maximum lift-drag ratio to just less than the angle of attack for maximum lift coefficient at both test Mach numbers. Generally, the model was more stable at the higher values of trim angle of attack.

INTRODUCTION

A number of configurations suitable for use as lifting manned reentry vehicles have been proposed and are being studied by the National Aeronautics and Space Administration. One such vehicle is a lenticular-shaped body with movable fins. This particular shape is of interest because it is compact - to reduce the structural-to-gross-weight ratio and the booster instability problem -, it has large radii

*Title, Unclassified.

of curvature - to reduce the aerodynamic heating rate -, and it has moderate lift capability - to reduce the deceleration load, increase entry corridor width, and provide maneuverability.

This paper presents the static longitudinal stability and control characteristics at Mach numbers of 2.86 and 6.02 of a lenticular-shaped reentry vehicle with and without movable fins. The investigation was conducted in the 2-foot hypersonic facility at the Langley Research Center at angles of attack up to about 95°. Reynolds number, based on the body diameter, was about 0.28×10^{6} at the Mach number of 2.86 and about 0.54×10^{6} at the Mach number of 6.02. Investigations of similar vehicles have been conducted at subsonic, transonic, and supersonic speeds. (See refs. 1 to 8.)

L
1
6
5
0

SYMBOLS

The force and moment coefficients were referred to the wind- and body-axes systems with the origin located longitudinally at 45 percent of the body diameter from the nose.

C_A axial-force coefficient, $\frac{\text{Axial force}}{qS}$

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment about } 0.45d}{qSd}$

C_N normal-force coefficient, $\frac{\text{Normal force}}{qS}$

$C_{p,b}$ base-pressure coefficient, $\frac{p_b - p_\infty}{q}$

d body diameter

L/D lift-drag ratio

M free-stream Mach number

p_b static pressure in model balance chamber

p_∞ free-stream static pressure

q free-stream dynamic pressure

S body planform area excluding fins

α angle of attack

δ fin deflection angle, positive when trailing edge down

MODEL AND APPARATUS

Details of the lenticular-shaped model used during this investigation are shown in figure 1, and photographs of the model are presented in figure 2. The body shape was generated by revolving an ellipse, having a major-to-minor-axis ratio of 2.73, about its minor axis. The horizontal fins were metal flat plates with the leading edges rounded and with vertical end plates on the tips. The fin deflection angle δ is the angle generated by rotating the horizontal fin about its hinge line and is positive when the trailing edge of the fin is deflected down. The end plates were rigidly attached to the horizontal fins so that the entire fin structure was deflected.

At angles of attack from -10° to 15° the model was supported by a straight sting which extended from the model base and was attached to the central support system of the tunnel. (See fig. 1(a).) In order to obtain angles of attack up to 95°, an adapter was inserted between the model and the sting. (See figs. 1(b) and 2(b).) This adjustable adapter was fixed at angles of 20°, 40°, 60°, and 80°, and the angle of attack of the model was varied about these settings by varying the angle of the central support system. These support systems kept the model near the center line of the tunnel at all angles of attack.

TESTS, CORRECTIONS, AND ACCURACY

Tests were conducted in the 2-foot hypersonic facility at the Langley Research Center at Mach numbers of 2.86 and 6.02. (See ref. 9 for tunnel details.) At the test Mach number of 2.86, the stagnation pressure was about 585 pounds per square foot absolute and the stagnation temperature was about 130° F; the Reynolds number, based on the body diameter, was about 0.28×10^6. At the test Mach number of 6.02, the stagnation pressure was about 7,250 pounds per square foot absolute and the stagnation temperature was about 330° F; the Reynolds number, based on the body diameter, was about 0.54×10^6.

Model forces and moments were measured with a three-component internal strain-gage balance. The measured coefficients are estimated to be accurate within the following limits:

C_N . . . . ±0.02
C_A . . . . ±0.004
C_m . . . . ±0.007

The angle-of-attack measurements were corrected for balance and sting deflections under load. The angle of attack is estimated to be accurate within ±0.2°. The base-pressure coefficients are estimated to be accurate within ±0.01.

Calibrations of the tunnel test section indicate that local deviations from the average free-stream Mach number in the region of the model were of the order of ±0.03. The average free-stream Mach number was held to within ±0.02 of the nominal values shown in this paper.

The effects of the presence of the support system were not determined during these tests and no corrections have been applied to the data to account for support interference. The axial-force and drag coefficients have not been adjusted to free-stream conditions at the model base.

RESULTS AND DISCUSSION

The variation of base-pressure coefficient with angle of attack for the body-alone model is presented in figure 3. Longitudinal aerodynamic data for the body-alone model are presented in figures 4 and 5 for Mach numbers of 2.86 and 6.02, respectively. The variation of base-pressure coefficient with angle of attack for the body-fin configurations with fin deflection angles of 20°, 0°, and -30° is presented in figure 6. Longitudinal aerodynamic data for these body-fin configurations are presented for Mach numbers of 2.86 and 6.02 in figures 7 and 8, respectively.

Body-Alone Model

The base-pressure data of figure 3 indicate the presence of a small difference in the support-induced interference effects of the straight sting and the high-angle adapter at the lower test Mach number of 2.86. This difference is also evident in the normal-force and axial-force data of figure 4. Differences between the interference effects of the two support mechanisms are negligible at the higher test Mach number of 6.02. The body-alone model with the center of gravity

located longitudinally at 45 percent of the model diameter was unstable for angles of attack less than about 40°. (See figs. 4 and 5.) At angles of attack greater than 40°, the model was stable. The trim angle of attack in this stable region for the body alone increased from about 67.5° at $M = 2.86$ to about 70.5° at $M = 6.02$.

The maximum lift coefficient for the body alone at both test Mach numbers was about 0.47 and occurred at an angle of attack of about 47.5°. The value for the maximum lift-drag ratio decreased from about 0.79 at $M = 2.86$ to about 0.73 at $M = 6.02$.

L
1
6
5
0

Body-Fin Model

The configuration with the fins at a deflection angle of 0° trimmed at an angle of attack of about 28.6° at $M = 2.86$ and about 32.2° at $M = 6.02$. (See figs. 7 and 8, respectively.) Deflecting the fins to -30° (trailing edge up) increased the angle of attack for trim to about 47.7° at $M = 2.86$ and about 51.0° at $M = 6.02$. The model did not trim for a fin deflection angle of 20° at the test Mach number of 2.86. However, the data seem to indicate that the model could be trimmed at some intermediate fin deflection angle at least down to an angle of attack of 6°, which was the lowest angle of attack at which data were obtained. At the Mach number of 6.02, the model with fin deflection angle of 20° did trim at an angle of attack of about 15.0° with neutral stability. Generally, the model was more stable at the higher values of trim angle of attack where the fin deflection angle was more negative.

Deflecting the movable fins gave the model a trim capability over the range from the angle of attack for maximum lift-drag ratio to just less than the angle of attack for maximum lift coefficient at both test Mach numbers.

The values of the maximum lift coefficient (0.635 at $M = 2.86$ and 0.622 at $M = 6.02$) for the body-fin model with a fin deflection angle of 0° represented increases of 35 percent over the values for the body-alone model. The maximum lift-drag ratio for the configuration with a fin deflection angle of 0° decreased from about 0.86 to 0.77 as the Mach number was increased from 2.86 to 6.02. These values represented increases in the maximum lift-drag ratio due to the addition of fins to the body-alone model of about 9 percent at $M = 2.86$ and about 6 percent at $M = 6.02$. A fin deflection of 20° (trailing edge down) increased the lift coefficient and lift-drag ratio over the angle-of-attack range investigated. Deflecting the fins to -30° decreased both the lift coefficient and lift-drag ratio.

CONCLUSIONS

Analysis of data from tests at Mach numbers M of 2.86 and 6.02 and angles of attack from -10° to 95° on a lenticular-shaped reentry vehicle with and without movable fins has led to the following conclusions:

1. The body-alone model with the center of gravity located longitudinally at 45 percent of the body diameter from the nose was stable at angles of attack greater than about 40° and trimmed within this stable region at an angle of attack of about 67.5° at $M = 2.86$ and about 70.5° at $M = 6.02$.

L
1
6
5
0

2. The value for the maximum lift-drag ratio for the body-alone model was about 0.79 at $M = 2.86$ and about 0.73 at $M = 6.02$.

3. Addition of the fins at a deflection angle of 0° to the body-alone model increased the maximum lift coefficient 35 percent, and increased the maximum lift-drag ratio about 9 percent at $M = 2.86$ and about 6 percent at $M = 6.02$.

4. Deflecting the movable fins gave the model a trim capability over the range from the angle of attack for maximum lift-drag ratio to just less than the angle of attack for maximum lift coefficient at both test Mach numbers. Generally, the model was more stable at the higher values of trim angle of attack.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., July 31, 1961.

REFERENCES

1. Ware, George M.: Static Stability and Control Characteristics at Low-Subsonic Speeds of a Lenticular Reentry Configuration. NASA TM X-431, 1960.

2. Mugler, John P., and Olstad, Walter B.: Static Longitudinal Aerodynamic Characteristics at Transonic Speeds of a Lenticular-Shaped Reentry Vehicle. NASA TM X-423, 1960.

3. Jackson, Charlie M., Jr., and Harris, Roy V., Jr.: Static Longitudinal Stability and Control Characteristics at a Mach Number of 1.99 of a Lenticular-Shaped Reentry Vehicle. NASA TN D-514, 1960.

4. Letko, William: Experimental Investigation at a Mach Number of 3.11 of the Lift, Drag, and Pitching-Moment Characteristics of Five Blunt Lifting Bodies. NASA TN D-226, 1960.

5. Demele, Fred A., and Brownson, Jack J.: Subsonic Longitudinal Aerodynamic Characteristics of Disks With Elliptic Cross Sections and Thickness-Diameter Ratios From 0.225 to 0.425. NASA TN D-788, 1961.

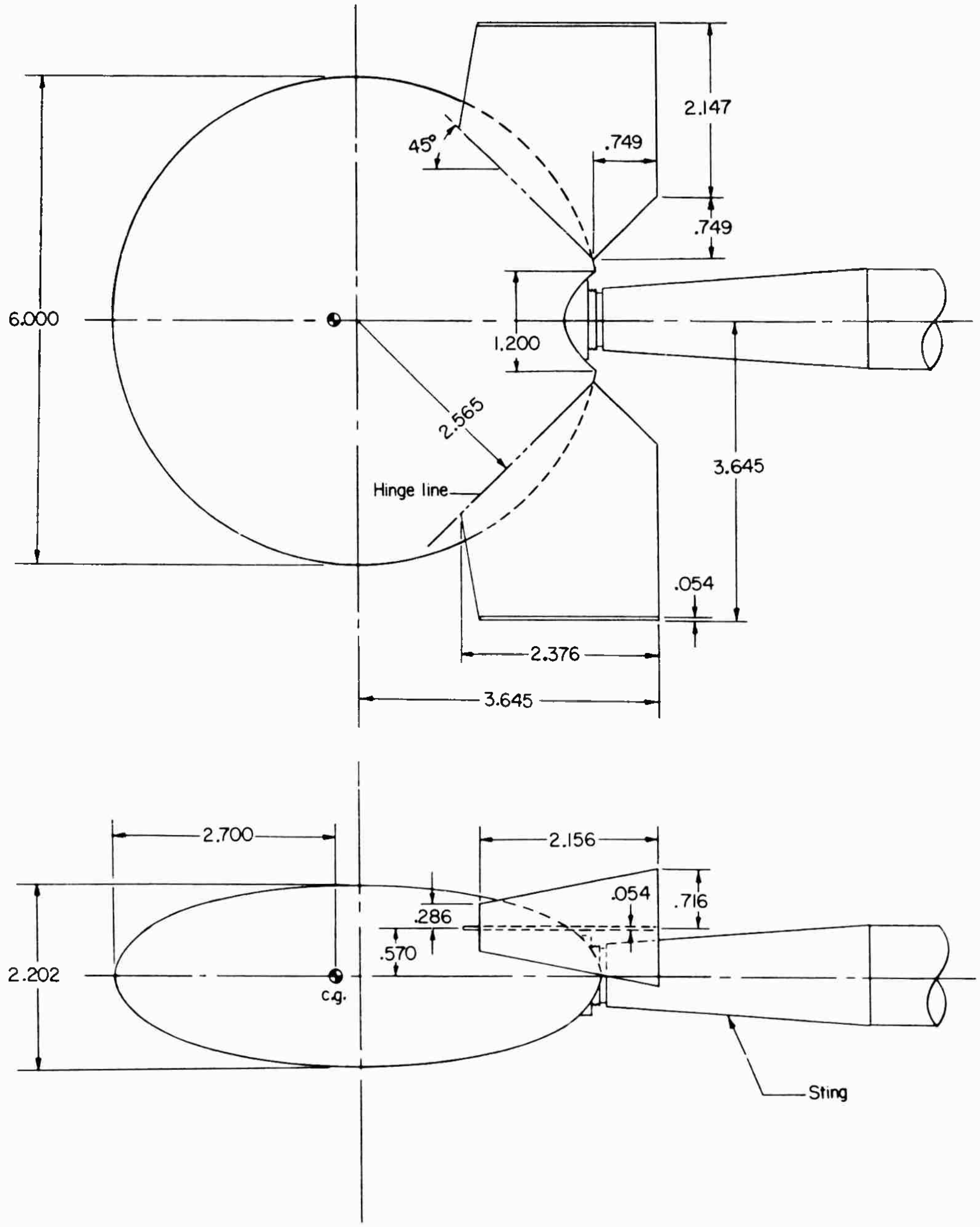
6. Demele, Fred A., and Brownson, Jack J.: Subsonic Aerodynamic Characteristics of Disk Re-Entry Configurations With Elliptic Cross Sections and Thickness-Diameter Ratios of 0.225 to 0.325. NASA TM X-566, 1961.

7. Lazzeroni, Frank A.: Aerodynamic Characteristics of Two Disk Re-Entry Configurations at a Mach Number of 2.2 NASA TM X-567, 1961.

8. Demele, Fred A., and Lazzeroni, Frank A.: Effects of Control Surfaces on the Aerodynamic Characteristics of a Disk Re-Entry Shape at Large Angles of Attack and a Mach Number of 3.5. NASA TM X-576, 1961.

9. Stokes, George M.: Description of a 2-Foot Hypersonic Facility at the Langley Research Center. NASA TN D-939, 1961.

L
1
6
5
0

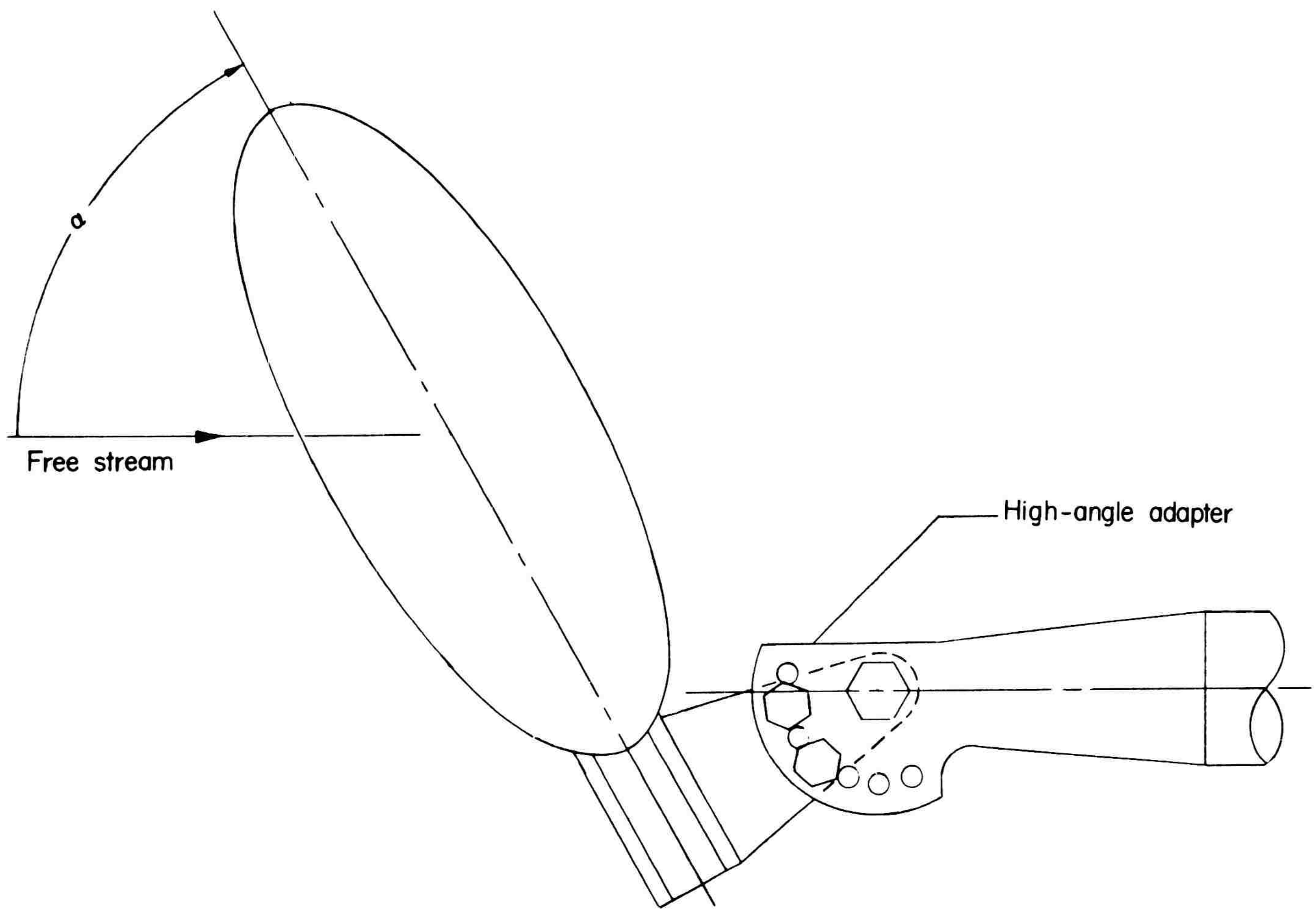


(a) Body-fin model on low-angle sting.

Figure 1.- Details of model. All dimensions are in inches unless otherwise noted.

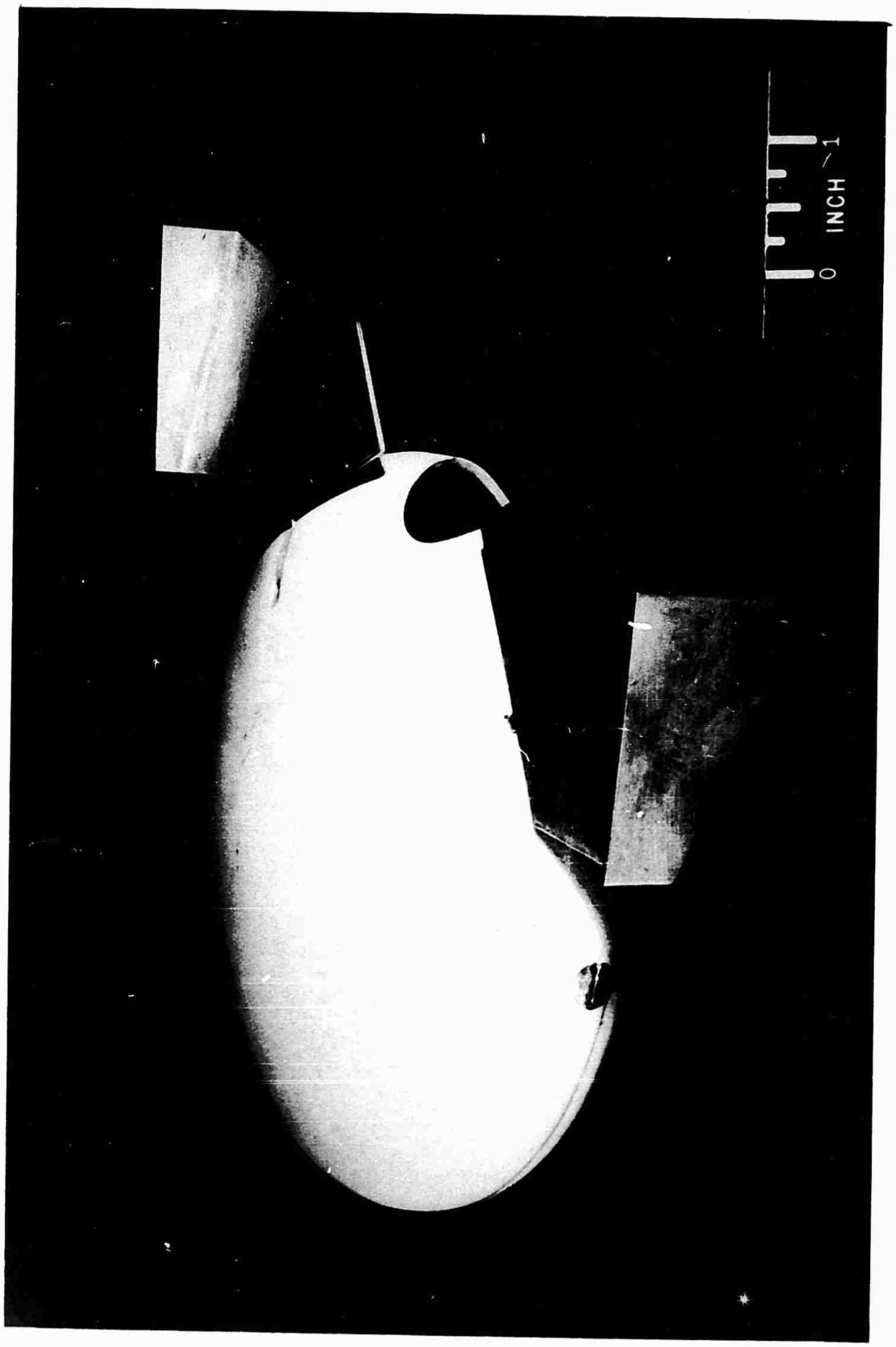
L-1650

L-1650



(b) Body-alone model on high-angle adapter.

Figure 1.- Concluded.



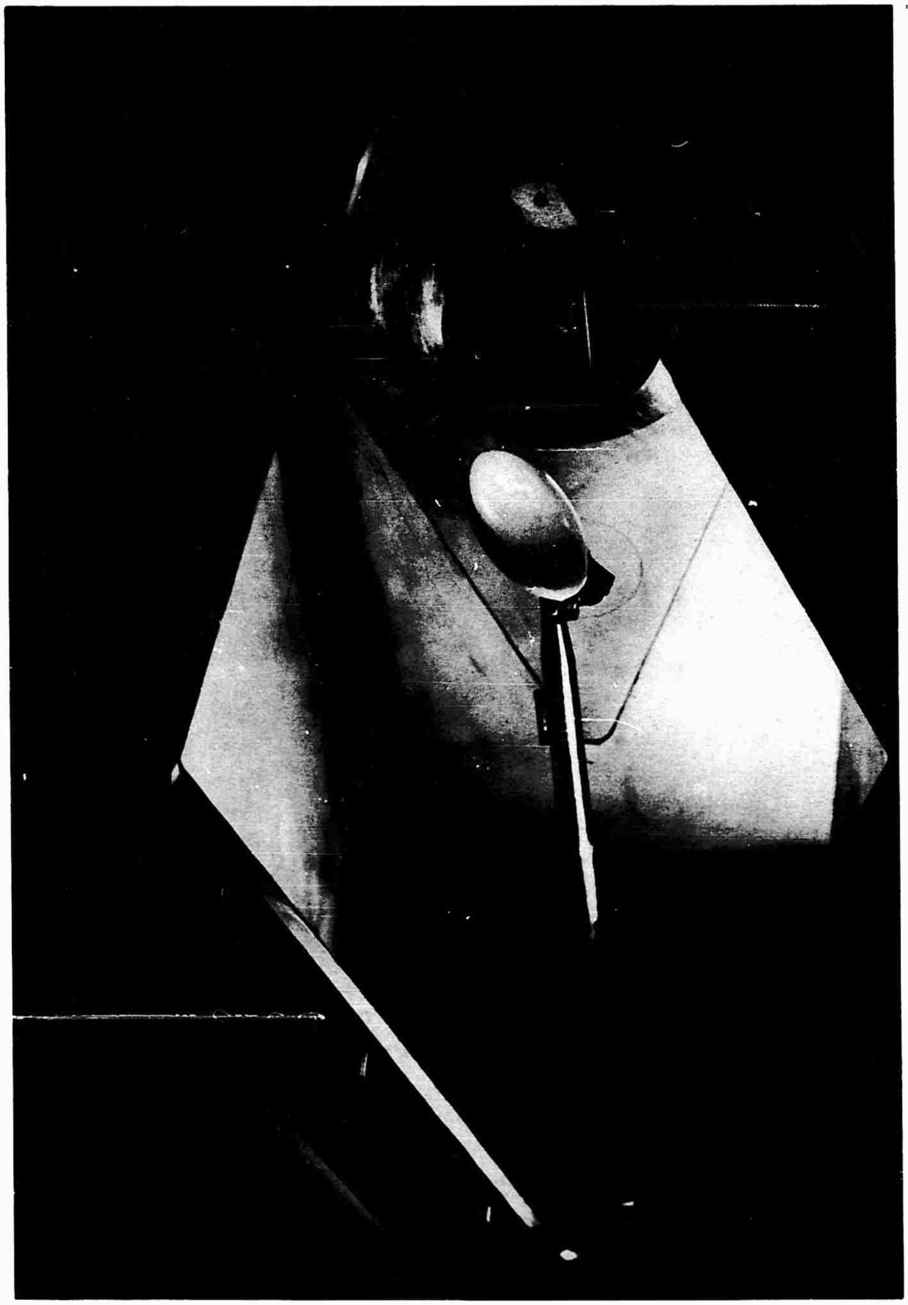
L-60-1634

(a) Body-fin model. $\delta = 0^{\circ}$.

Figure 2.- Photographs of model.

L-1090

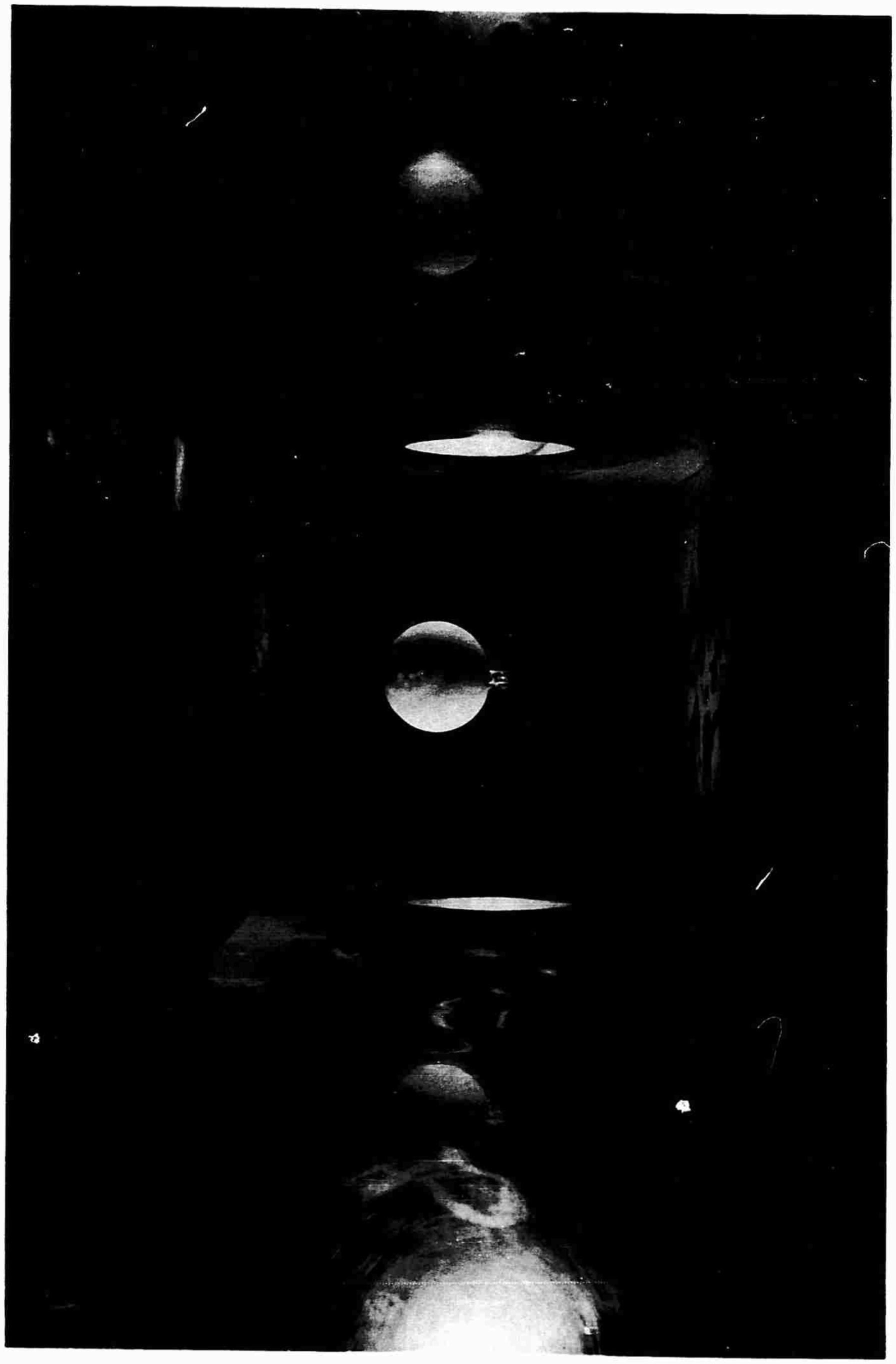
L-1620



L-61-1443

(b) Body-alone model shown mounted on high-angle adapter in 2-foot hypersonic facility at Langley Research Center.

Figure 2.- Continued.



L-61-1444

(c) Body-alone model shown mounted on high-angle adapter in 2-foot hypersonic facility at Langley Research Center (viewed from upstream).

Figure 2.- Concluded.

L-1650

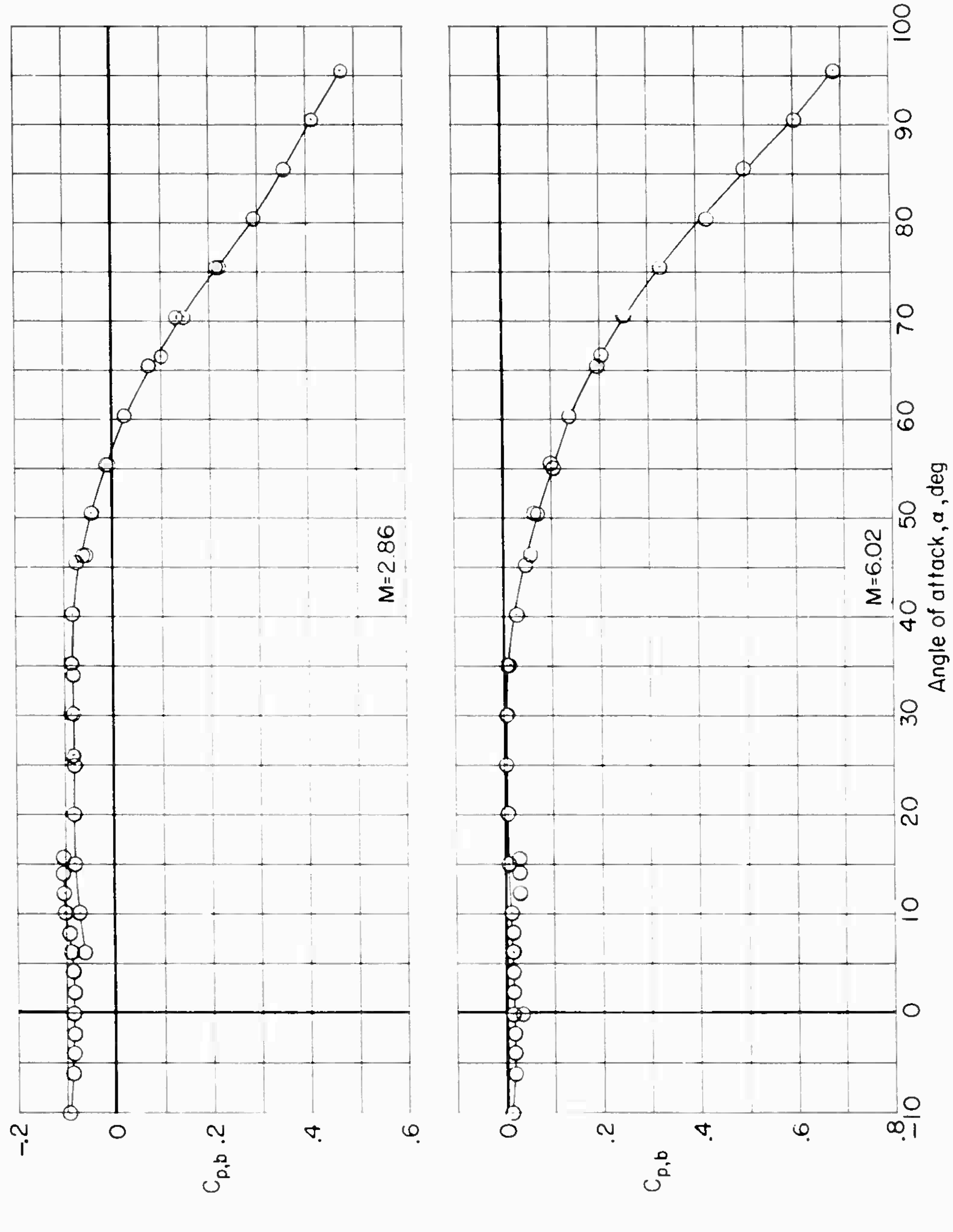


Figure 3.- Variation of base-pressure coefficient with angle of attack for body-alone model.

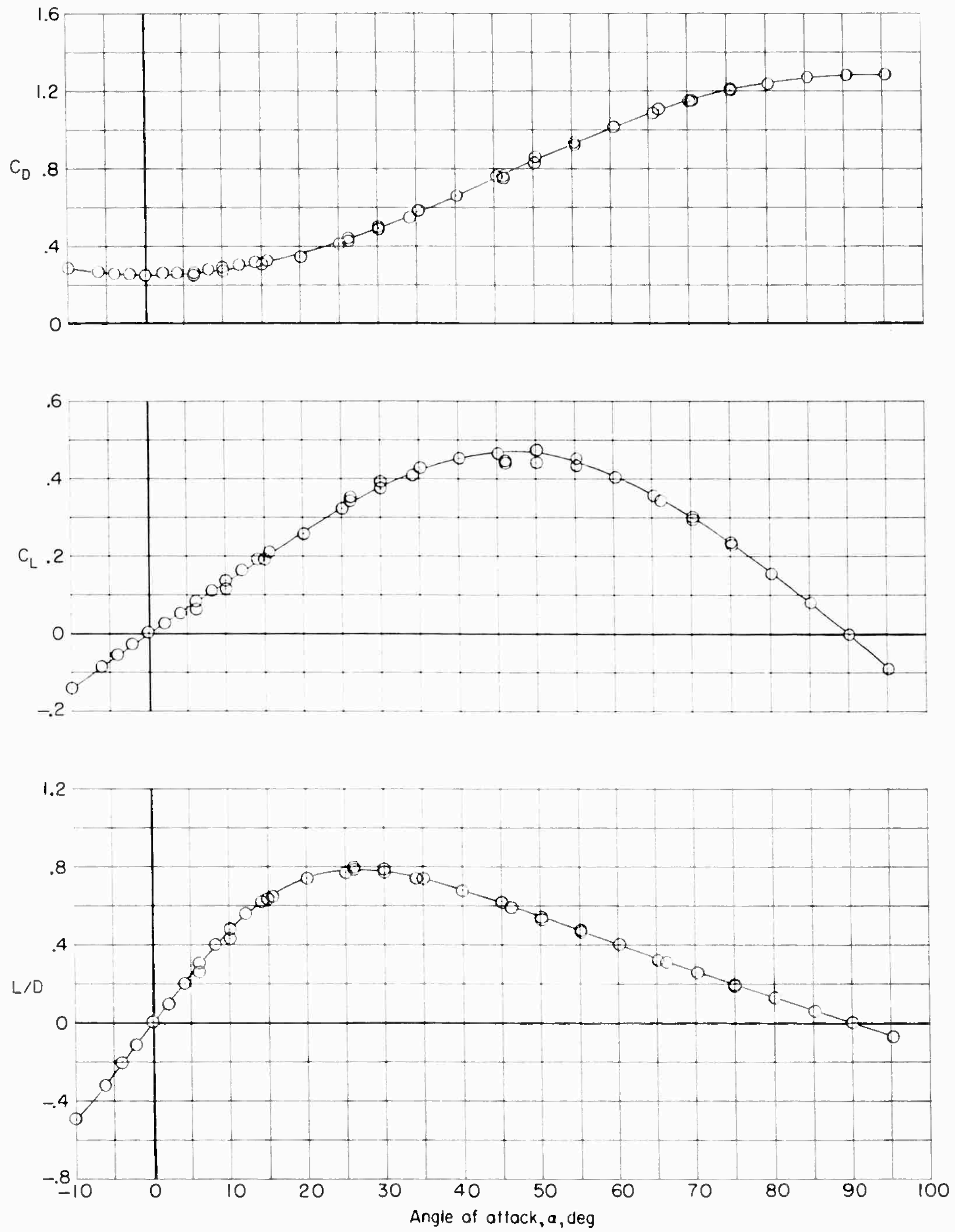


Figure 4.- Aerodynamic characteristics of body-alone model at a Mach number of 2.86.

L-1650

L-1650

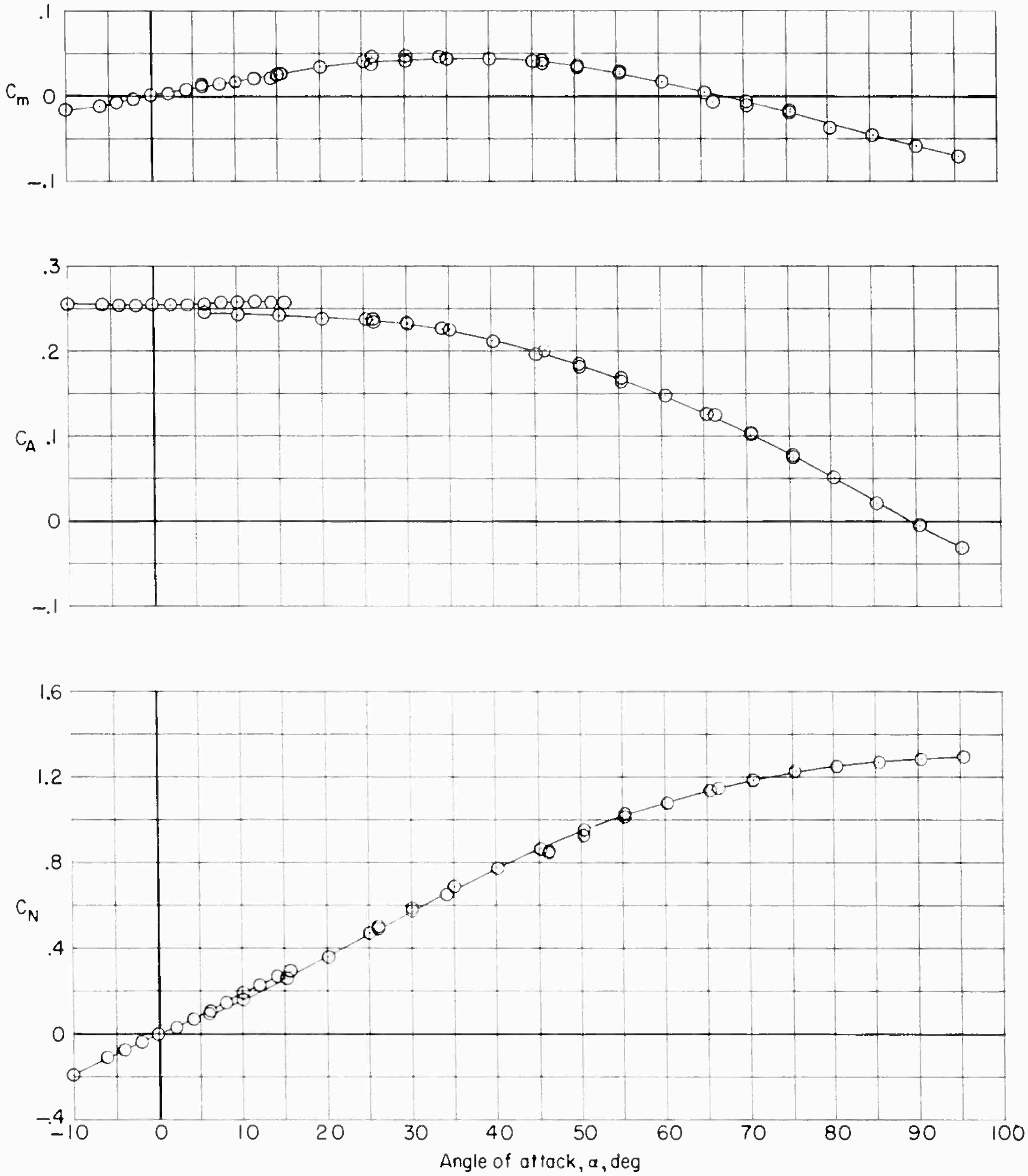


Figure 4.- Concluded.

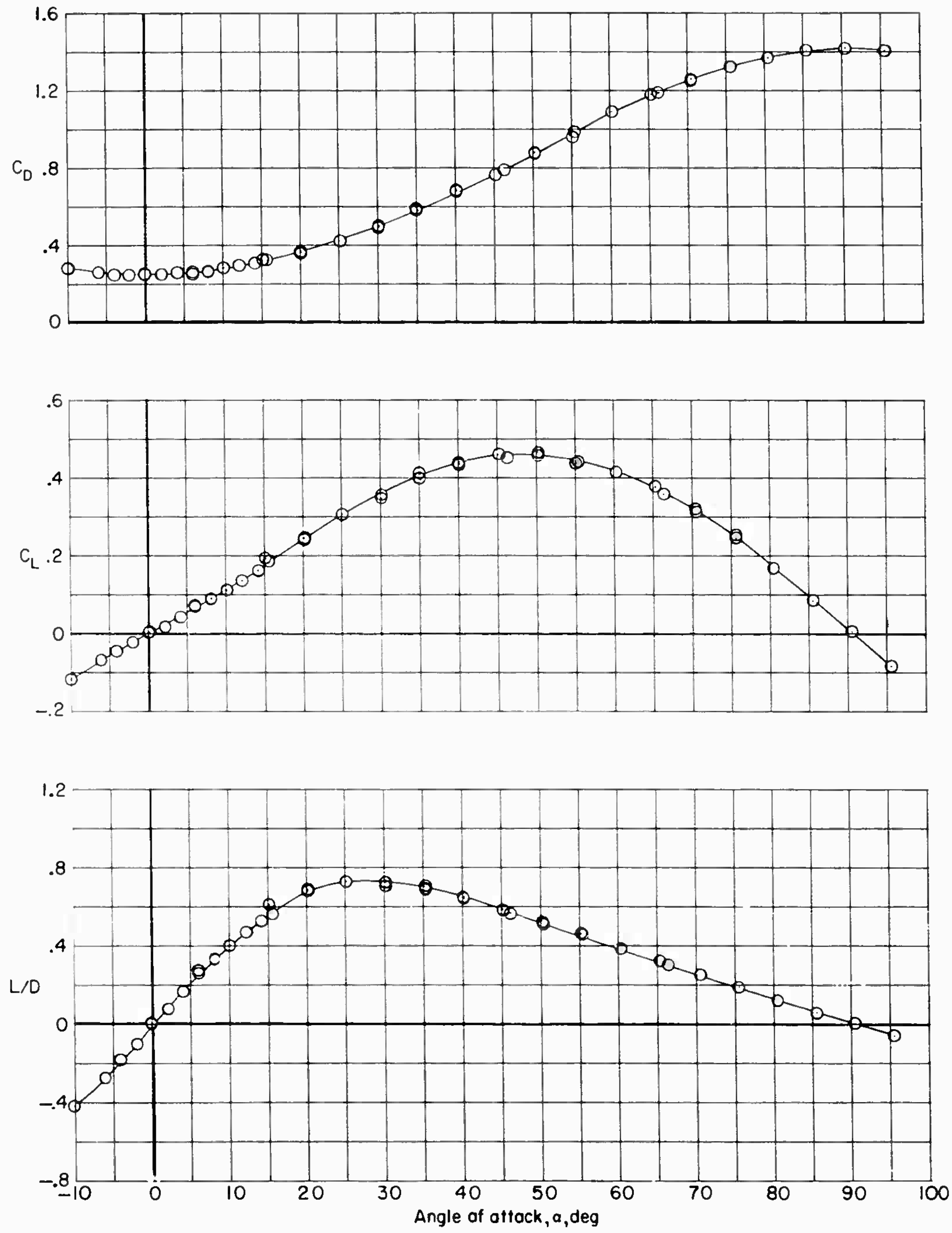


Figure 5.- Aerodynamic characteristics of body-alone model at a Mach number of 6.02.

L-1650

L-1650

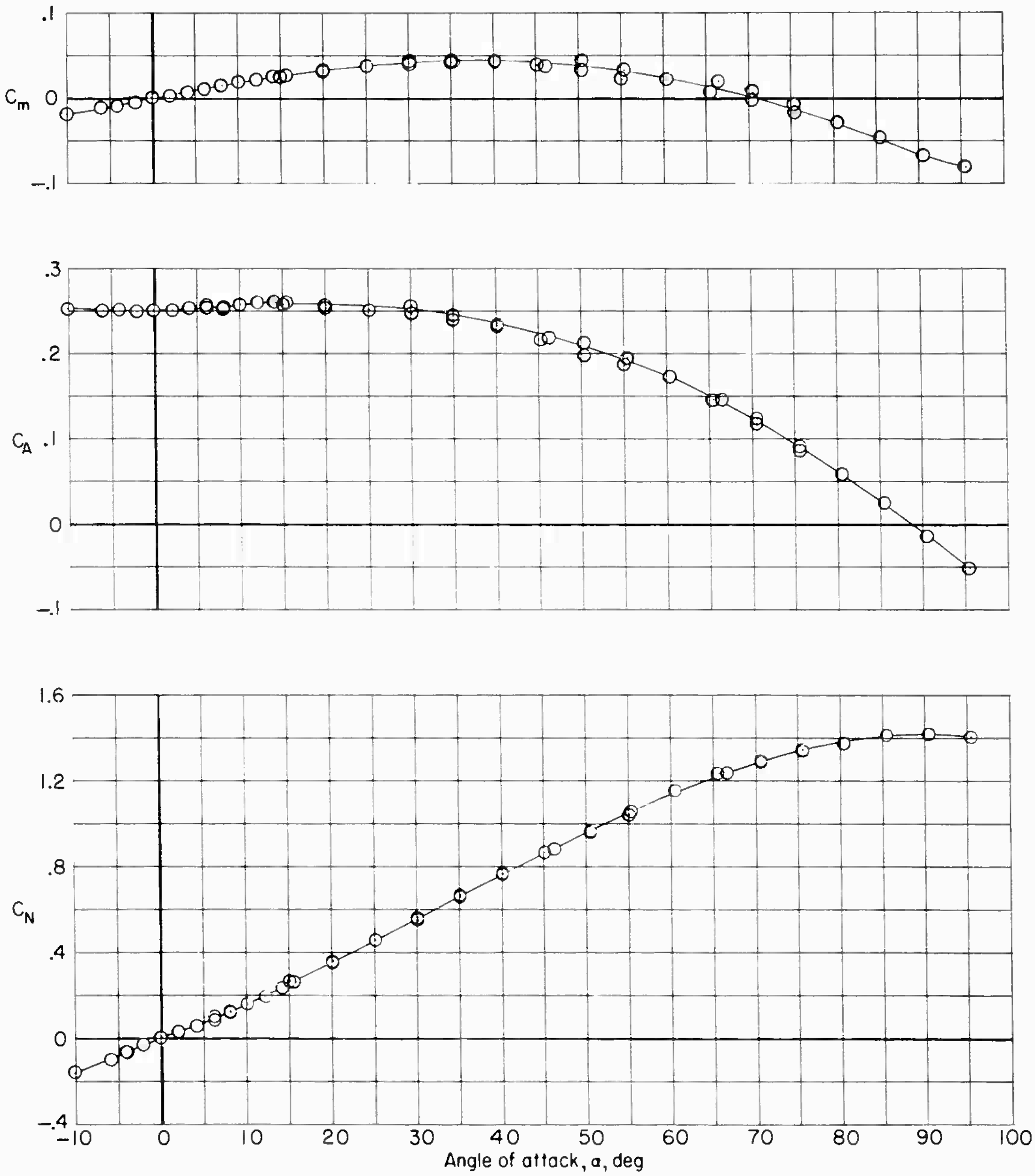


Figure 5.- Concluded.

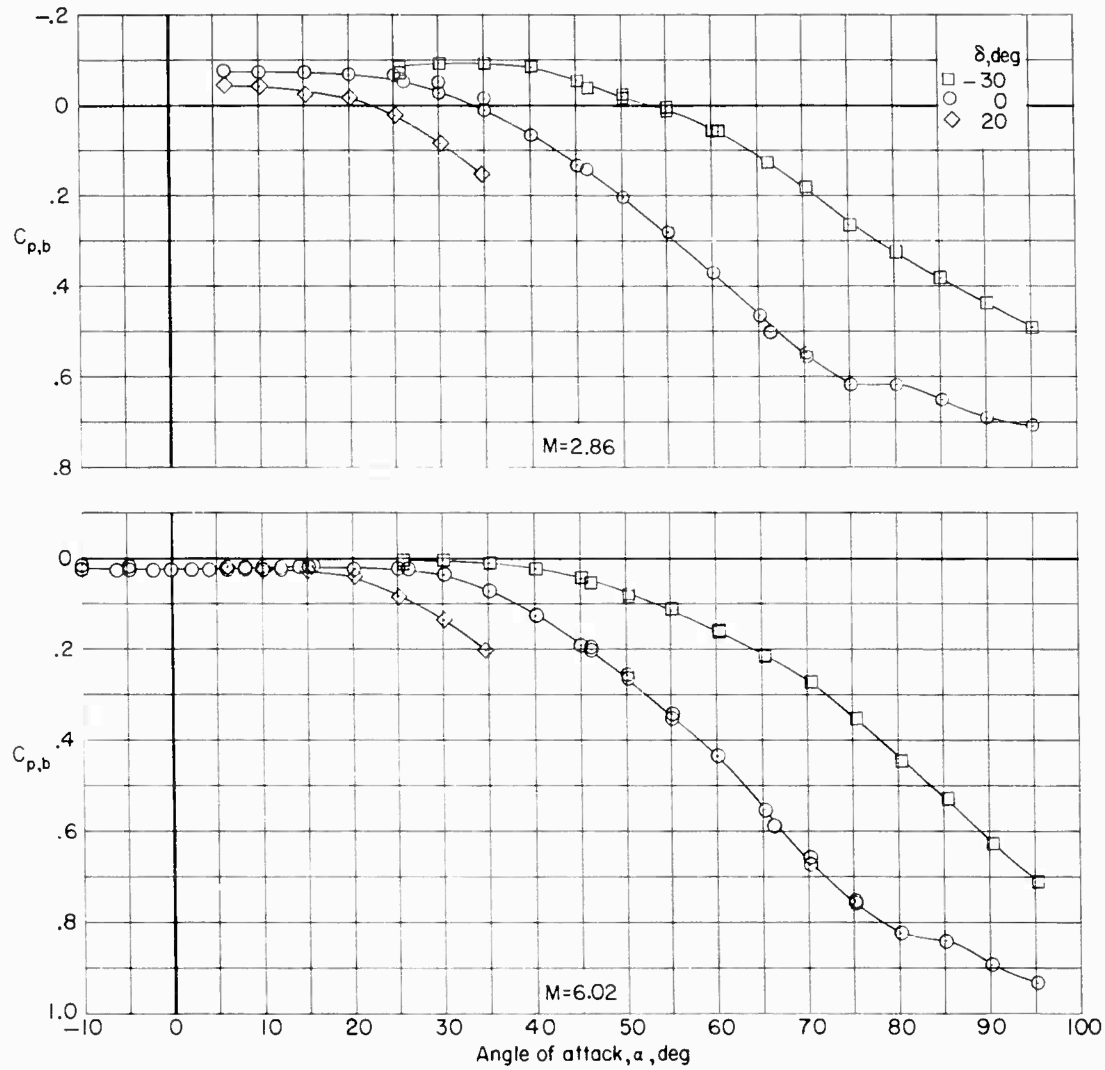


Figure 6.- Variation of base-pressure coefficient with angle of attack for body-fin model.

L-1650

L-1650

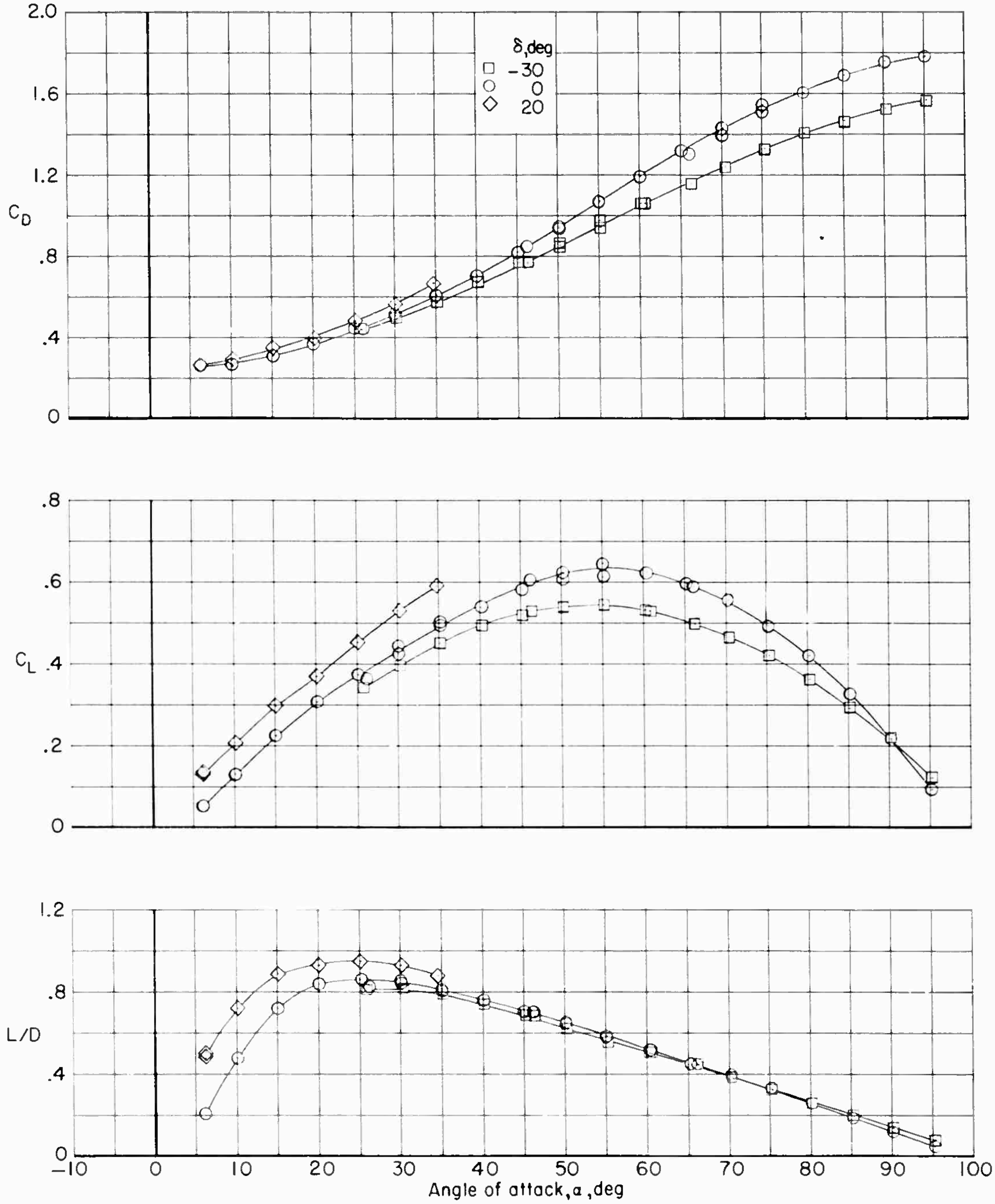


Figure 7.- Aerodynamic characteristics of body-fin model at a Mach number of 2.86.

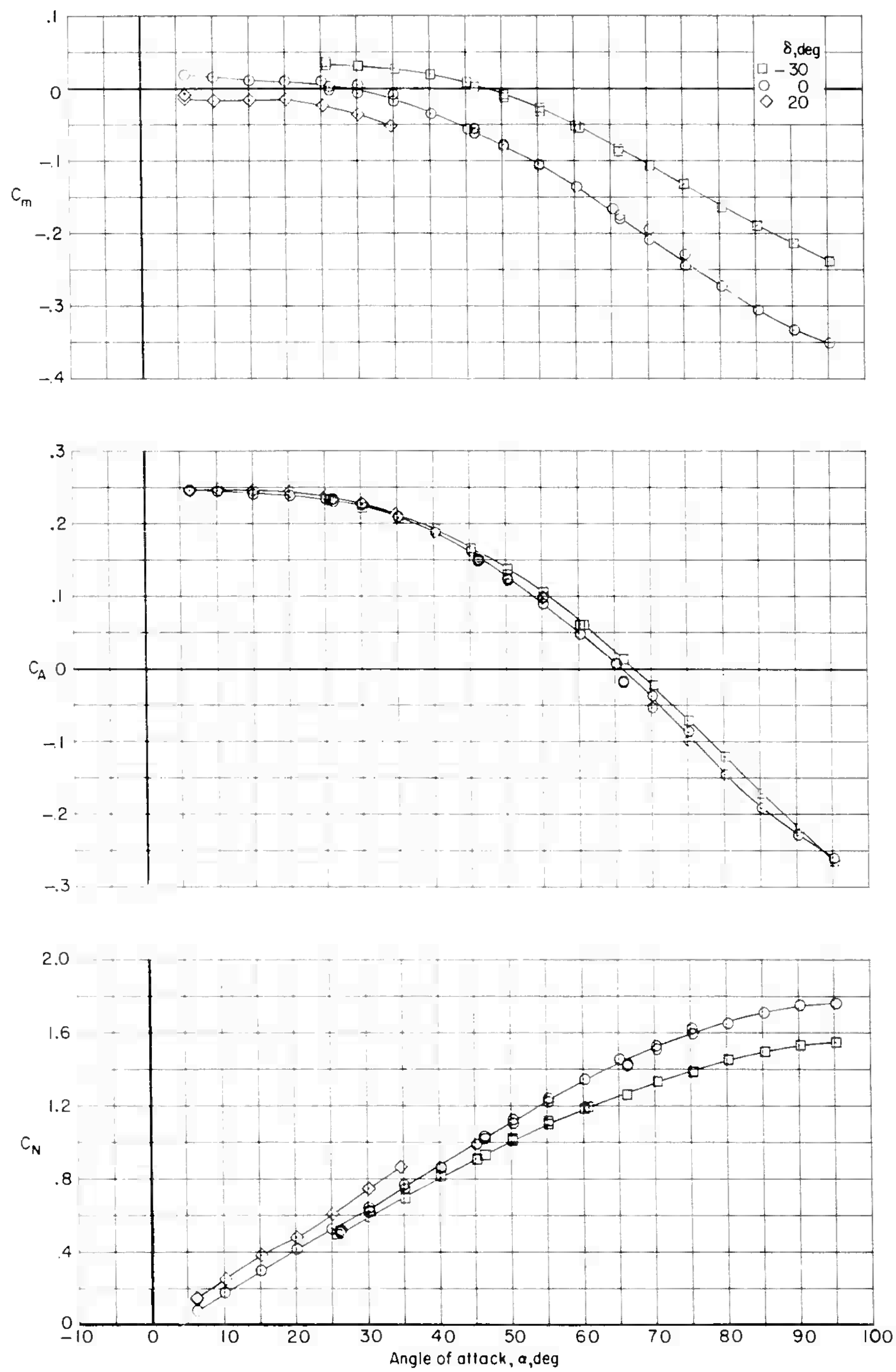


Figure 7.- Concluded.

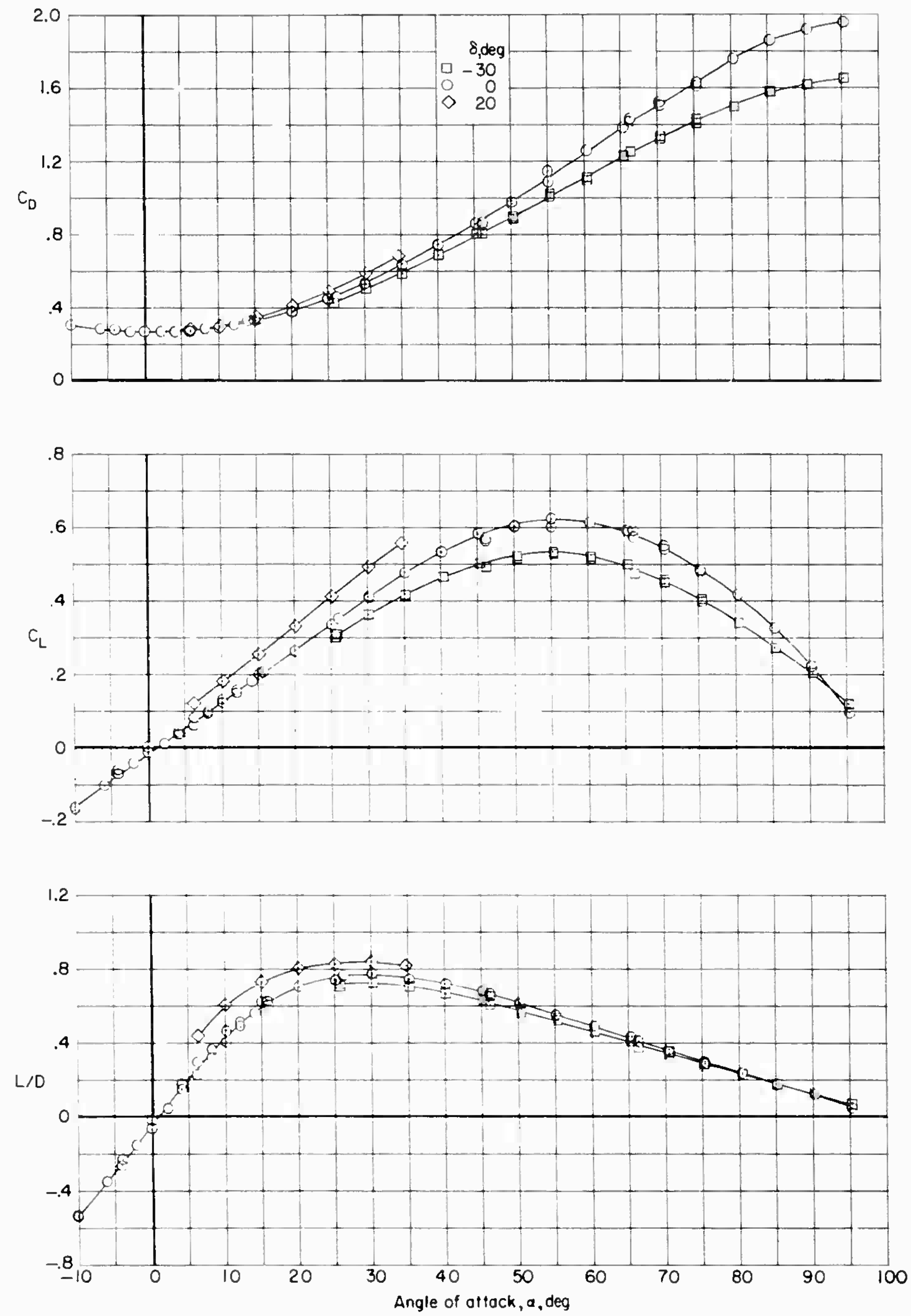


Figure 8.- Aerodynamic characteristics of body-fin model at a Mach number of 6.02.

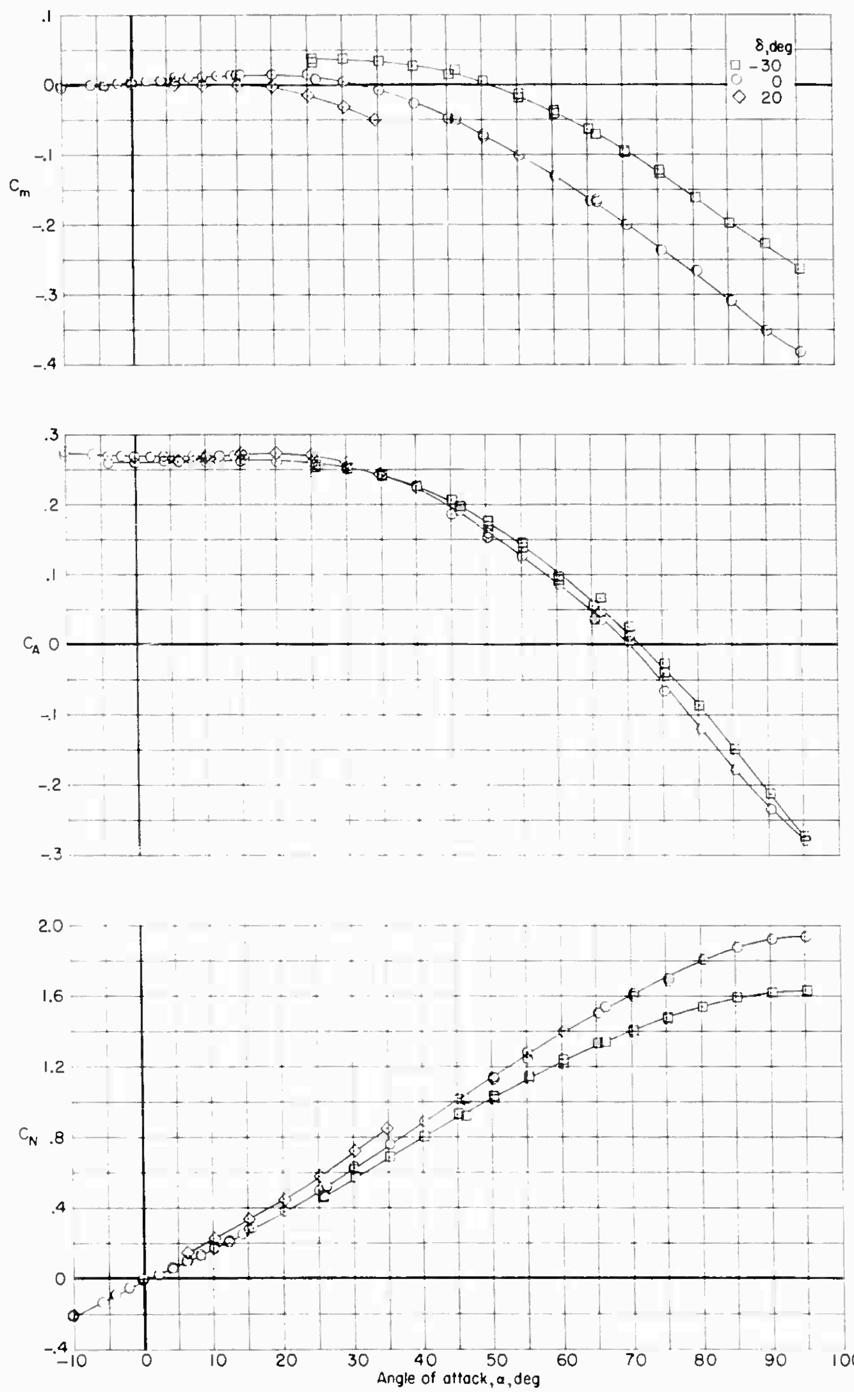


Figure 8.- Concluded.

NASA-Langley, 1961 L-1650

NASA TM X-621
National Aeronautics and Space Administration.
STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE.
Walter B. Olstad and Dewey E. Wornom. November 1961. 22p.
(NASA TECHNICAL MEMORANDUM X-621)
CONFIDENTIAL
(Title, Unclassified)

Tests were made at angles of attack from -10° to 95°. The Reynolds number, based on the body diameter, was about 0.28×10^6 at a Mach number of 2.86 and 0.54×10^6 at a Mach number of 6.02. The model was tested with and without movable fins. The fins were set at deflection angles of 20°, 0°, and -30°.

Copies obtainable from NASA, Washington

CONFIDENTIAL

I. Olstad, Walter B.
II. Wornom, Dewey E.
III. NASA TM X-621

(Initial NASA distribution:
2, Aerodynamics, missiles and space vehicles;
50, Stability and control.)

NASA

CONFIDENTIAL

NASA TM X-621
National Aeronautics and Space Administration.
STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE.
Walter B. Olstad and Dewey E. Wornom. November 1961. 22p.
(NASA TECHNICAL MEMORANDUM X-621)
CONFIDENTIAL
(Title, Unclassified)

Tests were made at angles of attack from -10° to 95°. The Reynolds number, based on the body diameter, was about 0.28×10^6 at a Mach number of 2.86 and 0.54×10^6 at a Mach number of 6.02. The model was tested with and without movable fins. The fins were set at deflection angles of 20°, 0°, and -30°.

Copies obtainable from NASA, Washington

CONFIDENTIAL

I. Olstad, Walter B.
II. Wornom, Dewey E.
III. NASA TM X-621

(Initial NASA distribution:
2, Aerodynamics, missiles and space vehicles;
50, Stability and control.)

NASA

CONFIDENTIAL

CONFIDENTIAL

I. Olstad, Walter B.
II. Wornom, Dewey E.
III. NASA TM X-621

(Initial NASA distribution:
2, Aerodynamics, missiles and space vehicles;
50, Stability and control.)

NASA

CONFIDENTIAL

NASA TM X-621
National Aeronautics and Space Administration.
STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE.
Walter B. Olstad and Dewey E. Wornom. November 1961. 22p.
(NASA TECHNICAL MEMORANDUM X-621)
CONFIDENTIAL
(Title, Unclassified)

Tests were made at angles of attack from -10° to 95°. The Reynolds number, based on the body diameter, was about 0.28×10^6 at a Mach number of 2.86 and 0.54×10^6 at a Mach number of 6.02. The model was tested with and without movable fins. The fins were set at deflection angles of 20°, 0°, and -30°.

Copies obtainable from NASA, Washington

CONFIDENTIAL

I. Olstad, Walter B.
II. Wornom, Dewey E.
III. NASA TM X-621

(Initial NASA distribution:
2, Aerodynamics, missiles and space vehicles;
50, Stability and control.)

NASA

CONFIDENTIAL

NASA TM X-621
National Aeronautics and Space Administration.
STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE. Walter B. Olstad and Dewey E. Wornom. November 1961. 22p.
(NASA TECHNICAL MEMORANDUM X-621)
CONFIDENTIAL

(Title, Unclassified)

Tests were made at angles of attack from -10° to 95°. The Reynolds number, based on the body diameter, was about 0.28×10^6 at a Mach number of 2.86 and 0.54×10^6 at a Mach number of 6.02. The model was tested with and without movable fins. The fins were set at deflection angles of 20°, 0°, and -30°.

Copies obtainable from NASA, Washington

CONFIDENTIAL

I. Olstad, Walter B.
II. Wornom, Dewey E.
III. NASA TM X-621

(Initial NASA distribution: 2, Aerodynamics, missiles and space vehicles; 50, Stability and control.)

NASA

CONFIDENTIAL

NASA TM X-621
National Aeronautics and Space Administration.
STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE. Walter B. Olstad and Dewey E. Wornom. November 1961. 22p.
(NASA TECHNICAL MEMORANDUM X-621)
CONFIDENTIAL

(Title, Unclassified)

Tests were made at angles of attack from -10° to 95°. The Reynolds number, based on the body diameter, was about 0.28×10^6 at a Mach number of 2.86 and 0.54×10^6 at a Mach number of 6.02. The model was tested with and without movable fins. The fins were set at deflection angles of 20°, 0°, and -30°.

Copies obtainable from NASA, Washington

CONFIDENTIAL

I. Olstad, Walter B.
II. Wornom, Dewey E.
III. NASA TM X-621

(Initial NASA distribution: 2, Aerodynamics, missiles and space vehicles; 50, Stability and control.)

NASA

CONFIDENTIAL

NASA TM X-621
National Aeronautics and Space Administration.
STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE. Walter B. Olstad and Dewey E. Wornom. November 1961. 22p.
(NASA TECHNICAL MEMORANDUM X-621)
CONFIDENTIAL

(Title, Unclassified)

Tests were made at angles of attack from -10° to 95°. The Reynolds number, based on the body diameter, was about 0.28×10^6 at a Mach number of 2.86 and 0.54×10^6 at a Mach number of 6.02. The model was tested with and without movable fins. The fins were set at deflection angles of 20°, 0°, and -30°.

Copies obtainable from NASA, Washington

CONFIDENTIAL

I. Olstad, Walter B.
II. Wornom, Dewey E.
III. NASA TM X-621

(Initial NASA distribution: 2, Aerodynamics, missiles and space vehicles; 50, Stability and control.)

NASA

CONFIDENTIAL

NASA TM X-621
National Aeronautics and Space Administration.
STATIC LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 2.86 AND 6.02 AND ANGLES OF ATTACK UP TO 95° OF A LENTICULAR-SHAPED REENTRY VEHICLE. Walter B. Olstad and Dewey E. Wornom. November 1961. 22p.
(NASA TECHNICAL MEMORANDUM X-621)
CONFIDENTIAL

(Title, Unclassified)

Tests were made at angles of attack from -10° to 95°. The Reynolds number, based on the body diameter, was about 0.28×10^6 at a Mach number of 2.86 and 0.54×10^6 at a Mach number of 6.02. The model was tested with and without movable fins. The fins were set at deflection angles of 20°, 0°, and -30°.

Copies obtainable from NASA, Washington

CONFIDENTIAL

I. Olstad, Walter B.
II. Wornom, Dewey E.
III. NASA TM X-621

(Initial NASA distribution: 2, Aerodynamics, missiles and space vehicles; 50, Stability and control.)

NASA

CONFIDENTIAL